Impact of Adverse Weather on Commercial Helicopter Pilot Decision-Making and Standard Operating Procedures

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Helicopter pilots face unique challenges with regard to adverse weather when compared to fixed-wing pilots. Rotorcraft typically operate at lower altitudes in off-field areas that are not always well covered by weather reporting stations. Although recent technological advances have increased the amount of weather data that pilots can access in the cockpit, weather remains a factor in 28% of fatal helicopter accidents. In this work, commercial helicopter pilots were surveyed and interviewed to better understand how they gather and process weather information, what the perceived limitations of current weather tools are, and how their decision-making process is affected by the information they gather and/or receive. Pilots were found to use a wide variety of weather sources for their initial go or no-go decision during the preflight phase, but use fewer weather sources in the cockpit while in-flight. Pilots highlighted the sparsity and sometimes inaccuracy of the weather information available to them in their prototypical operational domain. To compensate, they are forced to rely on local and experiential weather knowledge to supplement weather reports while still working to mitigate other external pressures. Based on the literature and on results from this work, recommendations are made to address the weather-related gaps faced by the rotorcraft community. This includes the installation of additional weather reporting stations outside of airports and densely populated areas, the further promotion of the HEMS tool to helicopter pilots in all industries, the development of weather tools capable of visualizing light precipitation such as fog, and the development of in-flight graphical displays that can help reduce the cognitive workload of interpreting weather information.

Nomenclature

$ACTA$	=	Applied Cognitive Task Analysis
$ADS-B$	=	Automatic Dependent Surveillance-Broadcast
AGL	=	Above Ground Level
$AMOA$	=	Air Medical Operators Association
$APSA$	=	Airborne Public Safety Association
AT	=	Air Tour / Air Taxi
ATC	=	Air Traffic Control
ATP	=	Airline Transport Pilot
$ASOS$	=	Automated Surface Observing System
$AWOS$	=	Automated Weather Observing System
EFB	=	Electronic Fight Bag

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FAA	=	Federal Aviation Administration
$FRAT$	=	Flight Risk Analysis Tool
FSS	=	Flight Service Stations
HAA	=	Helicopter Air Ambulance
HAI	=	Helicopter Association International
$HEMS$	=	Helicopter Emergency Medical Services
$HOWI$	=	Helicopter Operations Weather Information
HSA	=	Helicopter Safety Alliance
IFR	=	Instrument Flight Rules
$IHSF$	=	International Helicopter Safety Foundation
IMC	=	Instrument Meteorological Conditions
$IIMC$	=	Inadvertent Instrument Meteorological Conditions
LE	=	Law Enforcement
$NTSB$	=	National Transportation Safety Board
$PEGASAS$	=	Partnership to Enhance General Aviation Safety, Accessibility, and Sustainability
SOP	=	Standard Operating Procedures
TAF	=	Terminal Aerodrome Forecast
$TAWS$	=	Terrain Awareness and Warning System
$TOPS$	=	Tour Operators Program of Safety
$USHST$	=	United States Helicopter Safety Team
VFR	=	Visual Flight Rules
VMC	=	Visual Meteorological Conditions
$WTIC$	=	Weather Technology In the Cockpit

I. Introduction

The safety records of commercial aircraft operating under different Federal Aviation Regulation (FAR) Parts in the United States are inconsistent at best. While commercial air carriers flying under Part 121 have had a fatal accident rate of 0.006 per 100,000 flight hours over the last two decades [1], General Aviation (GA) operators flying under Part 91 and Part 135 have had a fatal accident rate closer to 0.80 per 100,000 flight hours [2]. This discrepancy has led the National Transportation Safety Board (NTSB) to identify safety improvements to Part 135 operations on their 2019-2020 most wanted list [3]. The Federal Aviation Administration (FAA) created the Partnership to Enhance General Aviation Safety, Accessibility, and Sustainability (PEGASAS), an FAA Center of Excellence, to address GA safety concerns [4]. This work is performed as part of PEGASAS Project 34, which investigates the effects of adverse weather and weather information on helicopter pilots' decision-making.

Many studies on GA safety focus on fixed-wing aircraft rather than rotorcraft, and are scoped such that a particular industry or geographical area is the primary focus, as outlined in Churchwell et al. [5]. Unfortunately, because of the significant differences in the types of operations performed by fixed-wing and rotary-wing aircraft, the applicability of these studies to rotorcraft is low. By design, rotorcraft typically operate at altitudes at or below 2,000 ft above ground level (AGL) and often have off-field landing sites, starkly in contrast to prototypical fixed-wing operations. In this context, aviation-specific weather sources often have the highest fidelity near airports and at high altitudes where fixed-wing aircraft operate, contrary to rotorcraft operations, and thus are less helpful to helicopter pilots. Additionally, while many fixed-wing aircraft are equipped to fly in instrument meteorological conditions (IMC), a large portion of the U.S. fleet of helicopters is not certified for instrument flight rules (IFR) operations. This lack of available weather information can put helicopter pilots at risk of encountering inadvertent instrument meteorological conditions (IIMC), which is a highly dangerous situation. This clearly motivates an investigation into the impact of adverse weather on commercial helicopter safety and how weather affects pilots' decision-making and standard operating procedures (SOPs) using an interactive, interview-based approach.

In this study, we focus on three types of helicopter operations, namely Helicopter Air Ambulance (HAA), Law Enforcement (LE), and Air Tour/Air Taxi (AT). We utilized a survey- and interview-based approach to gather information on how pilots operating in these mission areas retrieve and process weather information, what their perceived limitations of current weather sources and technologies are with regard to relevance, accuracy, latency, and other relevant metrics, and how their decision-making process is affected by the information they gather and/or receive. The paper is divided in to seven sections. In section II, we review the relevant literature for this study. In section III, we describe our survey- and interview-based approach and introduce the data and methods used for the survey and pilot interviews. In section IV, we analyze and discuss the results and themes obtained from the survey. In section V, we analyze and discuss the interviews realized on a sample of pilots from the three main mission areas of interest. In section VI, we summarize the main takeaways from both the survey and the interviews. Finally, in section VII, we conclude with the main contributions of this study and provide recommendations to decrease the occurrence of weather encounters during helicopter operations.

II. Literature Review

The vast majority of work done to understand the role that weather plays in aviation accidents has focused on fixed-wing operations. Included in this literature is a recent study completed in 2018. This work, identified several gaps in pilot decision-making with respect to weather information [6]. The primary gap that was identified by Caldwell et al. is that *"There is a limited understanding of how FAA - authorized weather information sources, as presented/displayed in the range of available tools (including mobile devices and software applications), influences pilot interaction with and use of weather information in degrading conditions."* However, this study focused primarily emphasized fixed-wing GA aircraft, largely leaving rotorcraft operations unaddressed. Consequently the findings do not directly carry over as fixed-wing and rotorcraft operations are distinct along a number of dimensions.

Of studies that have focused on rotorcraft safety, much interest has been placed on specific industries or areas, as explained in [5]. A number of studies have looked specifically at Helicopter Air Ambulance (HAA) operations due to their high risk, high visibility missions [1]. In 2006, the NTSB published its second special investigation report on HAA operations and identified four primary themes: inconsistent risk evaluation with versus without patients onboard, lack of flight risk evaluation programs for HAA-specific operations, lack of consistent flight dispatch services, and no requirements regarding the use of advanced technologies in the cockpit, such as Terrain Awareness and Warning System (TAWS) or weather radar [8]. These recommendations were made based on a case series of seven HAA accidents between 2002 and 2005. It was also noted that while only 38% of HAA flights occurred at night, nearly 50% of accidents occurred at night. This indicated a correlation between flight environmental conditions and the likelihood of an accident occurring.

Another short investigation of HAA accidents by Butler from 2000 to 2014 revealed that, of the 157 accidents analyzed, 30%, or 47 total accidents, were fatal [9]. Of the 47 fatal accidents, weather was a contributing factor in 47%, or 22 of them. The author recommended that the FAA raise the enroute weather minimums for FAR Part 135 operations, which HAA falls under, as a solution to this finding.

Widening the scope to all helicopter operations, weather was involved in 17% of all helicopter events (accidents and incidents) and 28% of fatal helicopter accidents between 2008 and 2018 [10]. This observation motivated a study on the existence of technological, training, skill or ability gaps related to weather for helicopter operations. Although a statistical analysis based on safety investigations similar to the one presented in [10] is useful to understand causal factors and accident types linked to weather, it is more difficult to identify human factors issues and decision-making chains that might have led to the accident. It also fails to capture strategies developed by pilots to avoid getting into a weather incident and the associated workload and cognitive demand. For this reason, we believe that a more personal approach based on surveys and interviews can complement a data analytic approach. Due to the intricacies of the situations faced by pilots and their risk mitigation strategies, in addition to the lack of literature utilizing helicopter operator interviews as safety-related evidence sources, we believe that an interview-based approach providing pilot feedback on operation-specific safety with respect to weather will produce novel conclusions.

III. Approach

This work consisted of two separate, but complementary, studies. The first is a survey to better understand pilots' flight operations, equipment and weather sources. The second is a semi-structured interview using the Applied

[1] HAA was previously referred to as Helicopter Emergency Medical Services (HEMS), but this terminology was officially phased out by the FAA in a 2015 Advisory Circular [7].

Cognitive Task Analysis (ACTA) method [11]. Both were designed to better understand pilot use of weather information both prior to flight and during flight. Details of each will be discussed in turn.

A. Survey

1. Survey Design

As part of the PEGASAS Project 34 data collection process, a survey was devised to supplement the NTSB statistics, understand the kind of weather information used by rotorcraft operators and get their opinion on the weather products that are available to them. The survey consisted of three main sections: 1) Demographics, 2) Flight environment, and 3) Safety Operations. The demographics section established the respondent's background (the respondent may be a pilot, a crew member, a dispatcher, a safety professional, etc.), including information about the piloting and/or flight crew experience if applicable (years of experience and the industry in which they accrued that experience). The second section collected information pertaining to the flight environments typical for the operations considered. This included geographical terrain, weather conditions, and weather-related information sources and/or instrumentation used by the operation. The third section pertained to the safety of the operations for each respondent. If the respondent had ever experienced a weather-related incident or accident, he/she was asked to describe the event along with the level of preparedness to handle the event. This was extended to also investigate the strengths or deficiencies of technologies used to prepare for and react to the event. The survey is available in Appendix I.

2. Survey Distribution

The survey targeted helicopter professionals whether they were helicopter pilots, crew, dispatch, or safety personnel. It was first published and distributed in January 2020 at HAI HeliExpo, and then was publicized in newsletters and websites in the helicopter community: newsletters (HAI Rotor Daily Newsletter, HSA Newsletter), websites (IHSF, USHST), and mailing lists (AMOA, Coast Guard, APSA, TOPS). The survey was closed in August 2020.

3. Survey Responses

The results of the survey were first filtered to only keep answers from respondents located in the United States who had completed the entire survey, yielding a total of 216 complete set of responses. Moreover, although the survey was also aimed at helicopter crew and dispatch personnel, 90% of the respondents were rotorcraft pilots. The results were filtered to only keep answers from helicopter pilots, and the analysis presented in the next section is performed on the resulting 194 U.S. rotorcraft pilots' answers to the survey. The anonymized survey dataset and its documentation are available at [12].

4. Survey Limitations

Although the survey was aimed at all professional helicopter pilots, it was answered largely by pilots with helicopter air ambulance (HAA) experience (70%). According to the FAA GA and Part 135 survey, HAA operations only accounted for 16% of all helicopter flight hours between 2008 and 2018. As such, it can be expected that HAA pilots similarly account for a smaller share of the American helicopter pilot population than 70%, and the survey answers cannot be considered fully representative of the entire rotorcraft pilot population. Nonetheless, it does provide useful insights into the weather experience of HAA and other helicopter pilots.

B. Interviews

1. Interview Design

The focus of the interviews was to gather more specific and descriptive information from pilots about their use of weather data, how weather impacts their regular operations, and specific examples of flights or situations in which weather had potential detrimental impacts on their operations. The goal was to substantiate our understanding of the cognitive challenges involved during adverse weather encounters and the cognitive processes that allow pilots to maintain situational awareness in the presence of adverse weather. Three pilots from each of the following industries were interviewed: HAA, Air Tour / Air Taxi (AT), and law enforcement (LE). The questions set developed by the authors was the same for all participants and available in Appendix II.

Specifically, the interviews followed the ACTA method developed by Militello and Hutton [11]. ACTA is designed to be a simple, broadly useful framework for an interviewer to extract information pertaining to the skills used by the interviewee to complete a task [11]. The purpose of using the ACTA framework in this analysis is that the methods are typically simple to implement, the questions guide both the interviewer and participant toward the research questions, and the outputted evidence of the interviews is typically clear and concise. Therefore, the participant is able to recall the relevant information and produce it in a coordinated and consistent manner for transcription.

The semi-structured interviews performed in this analysis were comprised of three unique stages: 1) Surface-level interview and task diagram, 2) Weather incident overview, and 3) Knowledge audit [13, 14]. Accordingly, the interviews were separated into distinct sessions by stage to prevent mental fatigue for both the interviewer and the interviewee. The full list of questions used to extract information from the transcripts can be found in Appendix III. Stage 1 of the interview process is a surface-level interview to depict the operation's standard operating procedures (SOP). The pilots were asked to describe their typical mission profile, identify any cognitively challenging aspects of their missions with regard to weather, and explain how they deal with degraded weather conditions. Stage 2 dives deeper into weather-related events that the pilot has encountered. This can include events such as flying into IIMC, dealing with conflicting weather information from various sources, flying IFR with significant external pressures, and more. For each event, the pilot is asked to describe a timeline of the event, along with a discussion of the weather information that they attended to and used for the corresponding flight. The final interview, Stage 3, is what is called a "knowledge audit". It steps back to a higher level of thinking once again, and facilitates a discussion of what the pilots pay attention to in-flight, how they stay focused and work efficiently in-flight, and what weather-related technologies help and/or hinder their operations and why. It also covers the pilot's opinions on their SOP, how the SOP could potentially be improved with regard to weather to enhance safety, and how they recognize when their missions will deviate from their SOP.

2. Interview Participation

A total of nine pilots representing HAA, Air Tour / Air Taxi (AT), and law enforcement (LE) were interviewed. The participants were recruited from the survey. The survey demographics allowed us to select a set of highly experienced, high hour pilots.

3. Interview & Analysis Protocol

Each interview was conducted using a video conferencing software with audio recordings saved for transcription purposes. The audio recordings for each interview were transcribed using the Otter.ai software [2] and reviewed for accuracy by the authors.

Following the transcription, a thematic content analysis was completed by two independent researchers. They sought to find common themes across four major research questions:

1) *How are pilots using weather information?*
2) *What is cognitively difficult about their use of weather information?*
3) *What are the cultural elements that influence their seeking and use of weather information?*
4) *Were there any common themes among weather incidents?*

Upon identifying the themes of interest, the transcripts were re-reviewed by both researchers independently to identify additional evidence for or against each theme. Quality control was achieved by calculating an inter-rater reliability metric, namely the Cohen Kappa Statistic κ [15] as shown in Equation 1. For this statistic, p_0 is the relative observed agreement among raters, and p_e is the probability of a chance agreement. In this case, p_e is assumed to be zero due to the negligibly small probability that the two raters randomly choose the same lines of text from the

[2] https://otter.ai

transcripts. Results with a Kappa statistic that falls within the range of $0.7 \leq \kappa \leq 1$ is considered to be acceptable for this study. This analysis was performed for three commercial rotorcraft industries: HAA, Air Tour / Air Taxi, and Law Enforcement.

$$\kappa = \frac{p_0 - p_e}{1 - p_e} \tag{1}$$

Inter-rater reliability scores of above 70% were achieved for all three industries analyzed, as shown in Table 1. As previously stated, an inter-rater reliability score of 0.7 or greater is acceptable.

Table 1 Kappa values for the three industries of interest

	Helicopter Air Ambulance	Air Taxi	Law Enforcement
κ	0.7239	0.7045	0.8273

IV. Survey Results

Almost all pilots who answered the survey reported using digital tools and graphical displays both during the preflight and enroute phases of flight. HAA pilots reported having access to panel-mounted displays more than other commercial helicopter pilots, who answered they rely predominantly on external devices and applications. The HEMS tool was found not to be used often outside of the HAA industry. Most pilots are satisfied with the weather information available to them, and almost all pilots reported having received recent IIMC training. HAA pilots had a higher reported rate of helicopter IFR currency than all others.

A. Weather Tools and Sources

Weather technology has changed appreciably in the last decade. In the 2012 study presented in Casner et al. [16], only 25% of pilots made regular use of direct weather products and rarely called briefers, whereas according to the FAA, [17] in 2017 about 96% of briefings were provided online. Following this trend, pilots responding to our survey largely reported using digital weather products. For the preflight phase, 92% of pilots reported using an online tool such as the aviation weather center website [3] or the HEMS weather tool [4], and 77% reported using mobile or tablet applications such as Foreflight [5]. Enroute, 91% of pilots reported using their radio to listen to automated weather reports such as AWOS and ASOS, while 92% of pilots also have access to a graphical weather display, either through a panel-mounted display or a mobile phone or tablet application. Radar data in the cockpit can be accessed through ADS-B IN, through satellite weather, or directly with an onboard weather radar. The survey results indicate that all pilots rely heavily on online tools. In Figures 1 and 2, respondents were categorized based on whether they reported having HAA experience or not. Both figures show some differences in tool usages. Performing a preflight risk assessment is mandatory for HAA pilots. It can be done through a dedicated Flight Risk Assessment Tool (FRAT), but is sometimes integrated in an Electronic Flight Bag (EFB). This explains why these two categories of tools are used at higher rates by HAA pilots. HAA pilots were more likely to report using a cockpit display for weather and less likely to use an additional device such as a phone or a tablet than non-HAA pilots. This points to a difference of in-flight weather equipment between industries.

When asked about the weather information sources they used for preflight or in-flight, pilots generally selected multiple sources: 81% of pilots selected 3 or more types of weather information sources for preflight. On average pilots selected 2.8 weather information sources when asked about their in-flight weather sources, while, on average, they selected 3.6 weather sources when asked the same question about preflight. Pilots have access to fewer weather information sources in-flight where they must divide their attention between checking the weather and flying the aircraft.

[3] https://aviationweather.gov/
[4] https://www.aviationweather.gov/hemst
[5] https://www.foreflight.com/

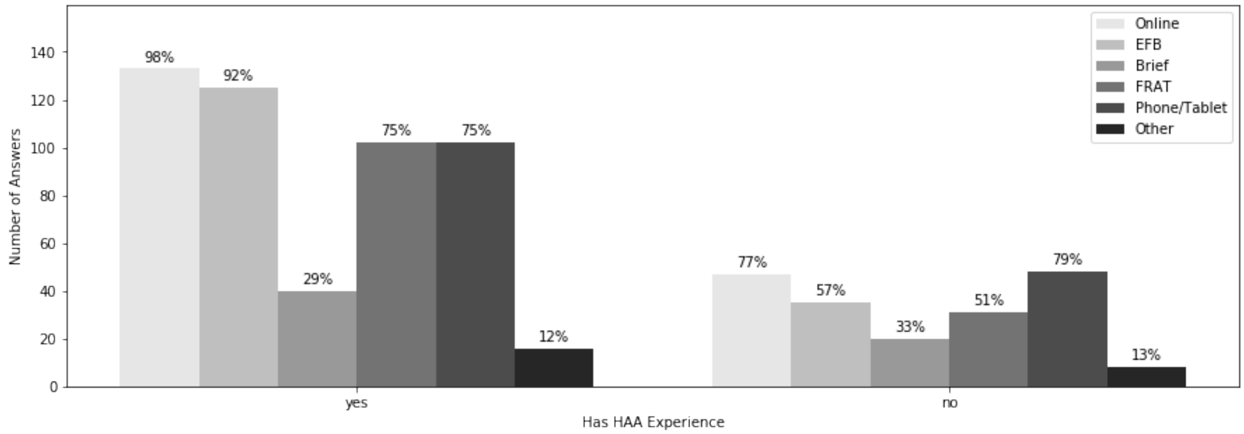

Fig. 1 Number of respondents by HAA experience who reported using each category of preflight weather information source (the percentages are by category of HAA experience)

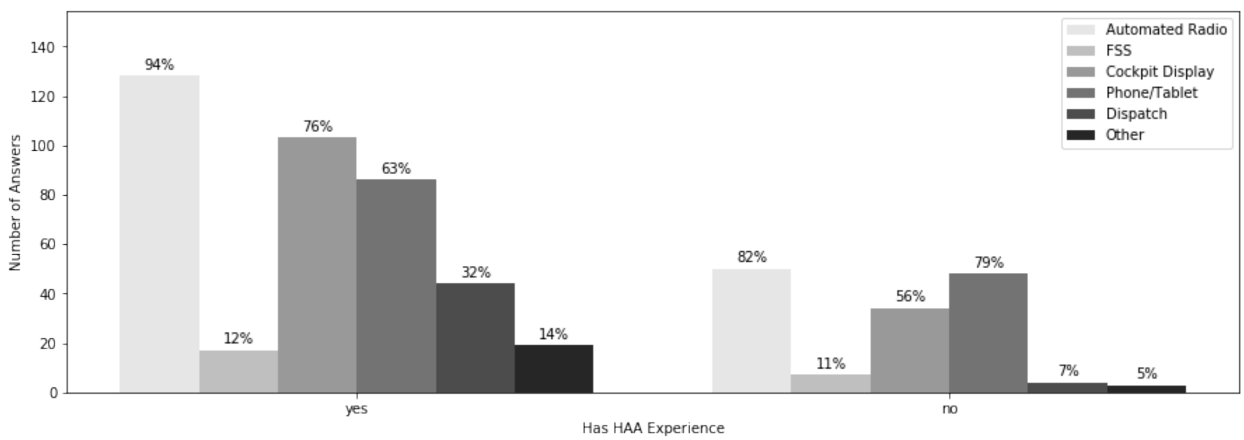

Fig. 2 Number of respondents by HAA experience who reported using each category of inflight weather information source (the percentages are by category of HAA experience)

Analyzing the answers of pilots who reported using online tools showed that 32% of all pilots explicitly mention the HEMS weather tool. However, of those 62 pilots, only 4 (6.5%) did not have HAA experience. It would therefore appear that the HEMS tool is underused outside of the HAA industry. Although the HEMS tool was originally developed for Helicopter Emergency Medical Services, its use is now encouraged for all types of low altitude helicopter operations. It provides a graphical display on which the user can overlay different weather information, including low altitude visibility data, which is especially relevant to helicopters who routinely fly between 800 and 2,000 ft AGL.

B. Opinion on Weather Products

When asked if the weather tools at their disposal were sufficient for safe operations, 71% of pilots answered positively. Among pilots who answered negatively, the most common complaint was the sparseness of weather stations. This complaint was also commonly recorded during pilots' interviews, as will be described in the subsequent section. Pilots who did not report HAA experience were less likely to report being dissatisfied with the weather tools at their disposal. This could be due to HAA pilots operating in more remote areas where they are more likely to find sparse weather stations or being asked to fly with less notice than pilots in other industries. However, no significant differences were found in terms of terrain of operations with respect to HAA experience. HAA pilots were slightly more likely to select city, flatland, and forests compared to non-HAA experienced pilots. Mountainous, suburban, and coastal terrain types were selected at the same rate between the two groups. It is worth noting than non-HAA pilot selected fewer terrain types than HAA pilots (an average of 2.6 against 2.9), which might indicate that they operate in a more restricted area. When asked specifically about weather tools latencies, 38% of pilots answered that latency could be a hindrance to safe operations.

C. Training for Weather-Related Emergency

Although almost all respondents (97%) had encountered or knew someone who had encountered adverse weather in-flight, these adverse weather events had not led to an incident or an accident in most cases (81%).

An analysis of the NTSB accident database showed that the most common type of fatal accidents caused by weather is Inadvertent Instrument Meteorological Conditions (IIMC) [10]. In the survey, 97% of pilots reported that they had received IIMC training: 90% of them received training within the past year and 69% of them received training within the last 6 months. This shows that a large majority of professional pilots are educated and trained for those conditions regularly, yet IIMC still remains the most common type of fatal accidents caused by weather [10]. An analysis of NTSB accident reports showed that fatal IIMC accidents often involved trained pilots. This could indicate that current training might not be sufficiently effective. However, being IIMC-trained should not be confused with being IFR current. In fact, only 56% of pilots reported being IFR current for rotorcraft operations. However, there are differences depending on the industry. Current regulations mandate that HAA pilots hold an helicopter IFR rating (currency not required) or an ATP certificate not restricted to VFR. As could be expected, 97% of pilots who reported having HAA experience were helicopter IFR rated, and only 60% were helicopter IFR current. Among pilots who did not report HAA experience, only 62% were helicopter IFR rated, and only 44% were helicopter IFR current. HAA pilots are more likely to be trained and current for helicopter IFR operations. This makes sense due to the nature of their operations. HAA pilots are more likely to report commonly operating at night (80% versus 52%) or under IFR (38% versus 13%) than other pilots. Finally, among pilots that reported having HAA experience, 58% also reported having military experience.

V. Interview Results

Across the four primary research questions, five primary themes were identified in this study:

1) Sparsity of weather sensing/reporting or lack of weather information
2) Reliance on local or experiential weather knowledge
3) Impact of current technology on safety
4) External pressures on weather-related decision-making
5) Distrust of weather information

The five themes cut across multiple research questions, and as such we will present them here independent from the research questions and then summarize their implications for the research questions in the Discussion section. These themes were identified due to not only the high percentage of pilots that mentioned them, but also to the number of times they were mentioned by each pilot. It should be noted that there are instances where pilots responded with similar comments to particular themes, but the evidence was either repetitive or simply not chosen for quotation. To better capture the scope of how many pilots truly spoke to a particular theme, a notation has been devised to identify how many pilots from each industry made similar comments. Each theme will be prefaced with the following notation (HAA | LE | AT), where the acronym will be replaced with the number of pilots that made similar comments for that respective industry. For example, since there were three interviewees per industry, if every single pilot spoke to a particular theme, the notation would be (3|3|3). This should assist with highlighting the trends identified in this study. A brief summary of the takeaways is described below and supporting evidence is presented in the subsequent sections.

For the first theme of weather sensing sparsity and lack of weather information (see §V.A), the interview responses indicate that there is significant overlap amongst rotorcraft pilots with regard to how they use weather information, despite the differences in their respective industries. All nine of the helicopter pilots across all three industries have experienced, and still deal with, the challenges associated with using weather information designed for fixed-wing aircraft operations rather than for rotorcraft operations. This presents itself largely in terms of sparse or unavailable weather information at sites of interest for helicopter operators, mostly for those who operate in environments away from airports (off-field).

For the second theme of reliance on personal experience (see §V.B), the interview responses indicate that when pilots reported a lack of sufficient weather information, they are often forced to rely on local or experiential knowledge of their flight environment to project the current visual conditions into the future. While local knowledge is a very valuable tool for pilots, it should be noted that it is not a viable substitute for a thorough check of all available weather sources both during preflight and in-flight. Some pilots reported trusting the visuals and the historical knowledge of their flight route so heavily that they would often disregard weather reports that presented information contrary to their own experiential projections.

For the third theme of current technology safety impact (see §V.C), the interview responses indicate that technology and the lack thereof play a significant role in what weather sources pilots use in-flight and also how they make weather-related decisions. Pilots indicated that over the years, weather technology has improved significantly, especially with the integration of graphical displays like NEXRAD [6], onboard radar, and even EFB-based tools like Foreflight. The biggest downside seemed to be that new weather technologies still experience latency sometimes in excess of 15 minutes, leaving pilots with inaccurate information simply because it was out of date. Additionally, modern radar tools still cannot detect and warn pilots of light precipitation conditions like fog, which can significantly reduce visibility and even cause IIMC events.

For the fourth theme of external pressure (see §V.D), the interview responses indicate the presence of external pressures on pilots is shown to be nearly universal. While the source of the pressures might have been different, the effect on the pilots was seemingly identical. External pressures cause tunnel vision, which detract from the pilots abilities to maintain situational awareness or focus on the big picture during flight. Mitigating external pressures can be done at both the personal and the organizational levels, and it is important to do so while establishing a proper safety culture.

For the final theme of weather information distrust (see §V.E), the interview responses indicate that pilots had experiences in which they were misled by weather information presented to them. Whether it was a lack of awareness of the inherent latency in the weather information received, or trusting a weather reporting source that was providing inaccurate data, pilots found themselves in dangerous situations. This reinforces the importance of using a variety of weather sources to validate incoming weather information and to allow for greater situational awareness, especially while in-flight.

Each of the following sections provides detailed discussion and evidence for each theme. The evidence is cited using the following notation: [Interviewee Code, Interview Stage, Transcript Line Number]. The interviewee code was randomly assigned to each interview participant, and is always prefixed by their industry (HAA, LE, or AT). As already discussed, there were three interview stages that evidence is drawn from.

A. Sparsity of Weather Sensing/Reporting or Lack of Weather Information

One of the most prevalent themes among all pilots was the sparsity of or complete lack of weather information available. All nine of the interviewed pilots (3|3|3) indicated that this is presently a hindrance to their day-to-day operations. They also noted that many of the aviation weather sources that are available to pilots are tailored to fixed-wing operations, as exemplified in the following interview transcript excerpt. Fixed-wing aircraft typically operate at higher altitudes and predominantly fly airport-to-airport missions. Conversely, rotorcraft fly slower, lower, and are specifically utilized for their maneuverability in off-field operations.

> *"I'd like to add one thing... a lot of that information is designed for fixed wing. There's very little information designed for rotorcraft... So I think that is definitely a helicopter challenge." [AT1, Stage 1, 568]*

Due to the off-field nature of some rotorcraft operations, a theme from pilots (3|1|2) was that weather information is sparse when flying to or from a location which is not near an airport/airfield. Most AWOS/ASOS stations are, appropriately, co-located at airports, meaning that location-specific weather data is often unavailable for helicopter pilots in their areas of interest. This means that they must rely on either a tool that interpolates weather data, such as the

[6] https://www.ncdc.noaa.gov/data-access/radar-data/nexrad

HEMS weather tool, or must do this themselves, often with no technological support. Additionally, the HEMS weather tool was frequently mentioned as a preflight resource, but due to the lack of availability in-flight, pilots seemingly lacked tools that could similarly display weather trends. This is noted by two pilots as follows:

> *"Most of the accurate weather is taken at airports, and the system is designed for airport to airport travel and we don't go there. We go everywhere but the airport, so you know we're flying off site..." [LE2, Stage 1, 272]*

> *"I have the weather here, my liftoff point, I have the weather at my destination. What's the weather in between? That was always the question mark." [HAA2, Stage 1, 176]*

Along these same lines, eight of the nine pilots (3|3|2) indicated that the lack of sufficiently detailed weather information had required them to alter their missions . Most often, this mission alteration would be due to preflight weather indications conducive to VFR followed by in-flight encounters with weather that either pushed or exceeded their allowable minimums, as exemplified in the following interview transcript excerpts.

> *"We accepted the mission VFR and proceeded out. And probably about 15-20 minutes into the mission, we started encountering some intermittent lower ceilings that were going to put us below our VFR minimums." [HAA3, Stage 2, 41]*

> *"Florida, summer, you know, afternoon we see thunderstorms building around the area. And then at one point we decided, hey, it's time to head back to the airport. Because we had no onboard weather, we had no iPad, no NEXRAD, nothing, just what was outside the window and reports from the tower." [LE2, Stage 2, 66]*

Finally, some of the interviewed pilots (1|2|2) mentioned that the most common weather type associated with mission interruption was fog. Fog is invisible on a radar, and therefore pilots indicated that they relied primarily on weather reporting stations to identify visibility concerns due to fog. When weather reporting stations or various other weather sources used by pilots fail to identify fog during a preflight check, it is often up to the pilots visual scanning and overall situational awareness to mitigate risks due to fog, as exemplified in the following interview transcript excerpt.

> *"I encountered just like kind of a misty fog. And I couldn't see it on radar...when I looked through ADS-B it didn't show anything, it looked like a clear flight. So, I was going along and visibility started to reduce...and I had to drop down, drop down a little bit and then I decided you know, I'll just quit." [LE1, Stage 2, 59-63]*

B. Reliance on Local Weather Knowledge or Past Experience

The second major theme identified in the interview process was a heavy reliance of pilots (3|2|3) on experiential knowledge of their respective operating environments. When weather sources or weather information are found to be sparse, missing, or incorrect, pilots indicated that they would immediately fall back on visual scanning and knowledge of the historical weather trends in their operational area. Decision-making, in that case, is mostly driven by pilots projecting their past experiences related to their flight route into the future, as noted below.

> *"...we have to take into account what weather we've historically seen based on the environment, and really that was a lot of our decision making, just kind of historical experience." [AT2, Stage 1, 243]*

It was also indicated that weather information for their local area can be "reliably inaccurate" to the point where one pilot joked that he expects the weather to always just be the opposite of whatever their local weather stations predict. This goes to show that the pilots tend to trust themselves and trust their own past experiences far more than they trust the data being provided to them externally, including by FAA-approved sources. This is exemplified by the following interview transcript excerpts.

“More often than not, you’re just as good at forecasting the weather as the guys at the National Weather Service are because you estimate those patterns coming through this region.” [HAA3, Stage 1, 262]

“The local area experience is worth its weight in gold. Absolutely, it really pays dividends when you know the trends in your area, how inaccurate the forecasts are...how things are going to play out.” [LE3, Stage 2, 185-187]

There are negative implications of pilots discounting certain sources of weather information. Some pilots indicated that they stopped checking notoriously inaccurate sources altogether, which implies that one less source of weather information is being used for each flight. According to the pilots, the best way to mitigate this is to posses and use a diverse set of weather sources and weather information to maintain a big picture view of the mission and catch any information outliers. However, the need to aggregate data from multiple sources puts a substantial strain on memory and cognitive resources.

It is also relevant to note that flights in marginal weather with ceilings of 1000 feet or less are a common practice among pilots interviewed (2|2|3). These low-ceiling flights indicate that pilots’ personal and company weather minimums are fairly aggressive, especially if this type of operation is frequent.

"So again, the whole time it was forecast for 600-800 foot ceilings, but it went down to I broke at bare minimums on that ILS at 200 feet. And when I actually came into land it was it was right on the edge of No, we’re going to make the go around." [HEMS1, Stage 2, 87]

"We knew we had marginal VFR weather, you know, close to 1000ft and 3 mi, but helicopter pilots operate in that kind of weather all the time." [LE3, Stage 2, 66-69]

When operating in poor visibility and/or low ceiling conditions, pilots are left to rely on their knowledge of the local area to complete their missions. While operating in marginal weather, pilots inherently have less margin for error, so it’s even more important that the weather information is accurate. Personal or organizational weather policies that allow for flight in degraded weather can significantly deter pilots’ abilities to make sound and efficient decisions while in-flight.

C. Impact of Current Technology on Safety

During the interviews, pilots were asked to provide examples when weather had significantly altered their plans. A number of pilots (2|2|0) mentioned events that occurred a decade or more ago and explained that with the technology available today, that event might not have happened to them. Pilots used to have to rely exclusively on radio reports and contact with Air Traffic Control (ATC) to estimate weather enroute. Today many pilots have a graphical display that is more detailed and easier to interpret. This is exemplified in the following transcript excerpts.

“Having, again, a higher quality of real time, weather reporting in the aircraft at the time, probably would have been the only thing that would have been able to help me.” [HAA2, Stage 2, 211]

“Our issue on that flight was a complete absence of technology that might help us. It was an older aircraft, old panel, and there was nothing on board for weather.” [LE2, Stage 2, 176-177]

Although new equipment has improved flight safety in some conditions, some pilots have reported that new technology was not helpful. Indeed, some low-altitude weather conditions such as fog are not picked up by radar or any other existing tools. This is noted in the following transcript excerpts.

“In this scenario, I really don’t see any technological deficiency other than, you know, the lack of weather reporting in the rural areas.” [HAA1, Stage 2, 289]

“And we do have live radar on the helicopter, but you know, we’re talking about lower ceilings, not really major showers and things, so it didn’t really do much.” [HAA3, Stage 2, 60]

The latency that many weather tools exhibit when displayed in the cockpit was an additional technological theme. Most of the pilots mentioned that they were aware of latency with weather tools, especially with onboard weather radar updated by satellite or through ADS-B (2|2|3). The frequency at which weather information is updated in-flight can change based on a wide variety of factors, including but not limited to, the type of weather data (AWOS/ASOS, Terminal Aerodrome Forecast (TAF) or radar), the type of data link (cellular, satellite or radio), the aircraft altitude, and the terrain in the immediate vicinity of the aircraft. If outdated information is displayed to the pilot by a weather source, it can lead to either false expectations regarding weather or confusion. One pilot even described a situation in which all three weather sources available to him in-flight displayed conflicting weather information, leading to his mission being cancelled and returning to base. This is noted in the transcript excerpt below.

> *"I know there's like a six-minute delay in the ADS-B and the NEXRAD...it seemed like there was a disconnect in what the aviation digital data service was showing, and what Foreflight was showing, and to what was actually there." [LE1, Stage 1, 308]*

In some cases, pilots also were unknowingly relying on outdated information. One pilot described a scenario in which a short-term lack of situational awareness about his XM weather radar led to a near accident. It goes to show that weather can develop and become a source of immediate danger to an operator and an aircraft in very short periods of time. This further highlights the importance of low latency, high refresh rate weather information, as described in the following interview transcript excerpt.

> *"I'm looking at the weather radar, and I'm not seeing anything. Well, I wasn't thinking about that 15-minute lag time. Well, during that 15-minute lag time all hell broke loose." [HAA2, Stage 2, 159]*

In addition to causing delays in weather data updates, one pilot (HAA3) mentioned that poor connectivity can prevent pilots from being able to communicate with ATC. This can be especially problematic as pilots must be in contact with ATC to request an IFR clearance, and are not legally allowed to enter IMC without being cleared.

One pilot (HAA1) emphasized that technology can overload the aviator who can sometimes focus more on his instruments than on what is happening outside. HAA3 stated that "technology is not the answer" and that more focus should be put on critical decision making rather than improving the technology even further.

D. Effect of External Pressures on Weather-Related Decision-Making

Another major theme that was common amongst many of the interviewed pilots (3|3|2) was the effect of external pressures on their weather-related decision-making. Each industry and each operator can be subjected to unique external pressures. For example, with HAA and some Law Enforcement operations, there are often lives on the line. One flight can directly influence whether a patient lives or dies, as noted below.

> *"you know, it's not supposed to affect our decision making, but we do have the added pressures of, you know, we're trying to get a patient to a hospital, whether he's on board or not, whether we're in route to the scene or in route to the hospital." [LE3, Stage 1, 235]*

Air Tour / Air Taxi operations, on the other hand, typically deal with pressures from the clients themselves. Especially for Very Important Person (VIP) transportation flights, customer satisfaction can be the difference between getting repeat business or being forced out of business entirely. For these types of operations, the only way to make money is to fly, leading to pilots taking more risks than they might in other fields. HAA and Law Enforcement operators can typically afford to be more risk-averse because their operations are more tightly governed and the monetary impact of turning down a single flight is much lower, as exemplified in the following interview transcript excerpts.

> *"... I want to take the flight, I want to make it fly. And so we do push...We stay within the limitations of the FAA, but we push it right to the limit...I've got a client going I want to go from here to there." [AT1, Stage 1, 367]*

"The customer is the most taxing part of the flight because as much as we try to not make it happen, there's going to be pressure from the customer...and we try to mitigate that as best as possible" [AT3, Stage 1, 533]

Despite the omnipresence of external pressures on pilots, many of them also mentioned both personal and company policies that attempt to mitigate the effects of these pressures which are industry-specific. For Air Tour / Air Taxi operators, external pressures require individual companies to set and reinforce solid safety criteria throughout the company leading to a safety culture for pilots to operate within. The actual rules and regulations for these types of flights allow for slightly more grey area in weather-related decision-making. This is noted below.

"That artificial need and desire to satisfy both your boss and your customer...What I need to keep reiterating to them is: don't do me any favors, okay? If the weather's crappy, cancel the darn flight well lose money but, you know, we're gonna lose a lot more money if we look at it that way" [AT3, Stage 3, 879]

For HAA and Law Enforcement operations, once again, there are distinct differences. Company or governmental policies for these industries tend to be stricter and are governed by formal policies and procedures that are well-documented. These operations typically will adhere precisely to the weather policies outlined in their general operations manuals (GOMs) and/or standard operating procedures (SOPs), as mentioned in the following interview transcript excerpt.

"So, in a HEMS world, what dictates the weather that you need? Number one is what the Part 135 operation vendor has in his general operations manual what we refer to as the GOM. The general operations manual gives you your weather criteria that you're allowed to fly in, which is then signed off by the Federal Aviation Administration." [HAA2, Stage 1, 139]

For all types of operations, its very important that the external pressures are mitigated as best as possible. This is often done in two main ways. First, by providing context of the full consequences of pushing the limits. Second, by implementing a safety culture and safety policies that support pilots making conservative weather decisions. Rewarding risky behavior would be the antithesis of this, so extreme risk-taking must be discouraged at all costs, as exemplified below.

"The general rule is you don't want to risk killing three to save one...You got three people, highly trained nurse, paramedic and a pilot. If I go out there and ball it up trying to get to one versus being a little conservative, I take that asset off the playing field, and it can't help anybody." [HAA1, Stage 1, 582]

"We have the full support of the agency if we make an enroute weather decision to turn around and go home" [LE3, Stage 1, 269]

E. Distrust of Weather Information

Pilots finally emphasized that weather information tends to either be misleading or to fail altogether in its purpose (3|3|1). In some cases, as previously mentioned, pilots indicated that they have a personal policy to ignore specific weather sources in their area. This, however, would constitute local or experiential knowledge. Pilots with less experience, or pilots operating in an unfamiliar environment, would not have knowledge of the misleading or inaccurate weather sources, and therefore would be required to spend more cognitive effort to decipher the disparity among sources. This is exemplified in the following interview transcript excerpts.

"Our aviation weather forecasts here are notoriously inaccurate, and you learn to deal with it. And you take that into account and you have built-in safety measures for that." [LE3, Stage 1, 211-212]

"For us being in 2020, it never ceases to amaze me how inaccurate [the forecasts] are..." [HAA3, Stage 3, 30]

Due to the readily available diverse technology for their operations, some pilots, especially in the HAA and Law Enforcement fields, indicated that they always checked multiple weather sources and used as much technology as they could to get the full picture of their flights. For example, multiple pilots revealed that they have used Night Vision Goggles (NVGs) to identify clouds or fog layers that were invisible to the naked eye and were also unreported by local weather reporting stations, as noted below. It is important to also note that radar-based technologies are currently incapable of detecting light cloud and fog layers.

> *"There's been times I've taken off from an airport that's reporting VFR, and we start going out and I can see through the goggles, that there's an unreported cloud layer just outside of the airport. If you look under the goggles, you can't see it." [LE2, Stage 2, 256-258]*

F. High Workload Due to Weather

While not an explicit theme identified in the analysis, it is pertinent to discuss the relatively high workload experienced by helicopter pilots. Most interviewed pilots (2|2|2) alluded to experiencing high cockpit workloads, especially when there is adverse weather in their respective flight paths. Several pilots (2|1|1) mentioned strategies, policies, or equipment that exists to mitigate high workloads. This includes autopilots, good crew resource management, and enforcing a sterile cockpit in the presence of adverse weather. Others (1|1|1) emphasized how accessing in-flight weather information can be challenging because flying a helicopter (especially without an autopilot) necessitates two hands on the controls at all times. This is illustrated by the following quote:

> *"When you're trying to fly in a single pilot aircraft that is not equipped with an autopilot or anything like that, the cockpit does get rather busy at that point in time." [HEMS2, Stage 2, 107]*

The adverse effects of a high pilot workload can be mitigated when there is a co-pilot or a flight officer in the cockpit. Having a trained aircrew or flight officer appeared common in the law enforcement domain, but was not highly represented in the other industries. In HAA, the medical crew is trained to watch outside the aircraft for valuable information to report to the pilot, but once a patient is onboard their focus is diverted to providing the requisite medical attention. One Air Taxi pilot (AT3) mentioned flying with another pilot in marginal weather conditions, but also emphasized that this is a very rare occurrence.

VI. Discussion

We began this investigation as an effort to address the following research questions:

1) *How are pilots using weather information?*
2) *What is cognitively challenging about their use of weather information?*
3) *What are the cultural elements that influence their seeking and use of weather information?*
4) *Are there any common themes among weather incidents?*

As previously discussed, the most common themes identified from the pilot interviews were sparsity of weather sensing/reporting or lack of weather information, reliance on local or experiential weather knowledge, impact of current technology on safety, external pressures on weather-related decision-making, and distrust of weather information. These themes were identified while investigating the aforementioned research questions, and they shed light on the some of the answers.

The survey and interviews gave the researchers an insight into what types of weather tools are being used among pilots of different operation types and backgrounds. Pilots use many different tools to gather weather information, both from FAA-approved sources and other supplementary sources. It was also indicated that pilots within the same organization habitually gravitated toward the same tools. During preflight, pilots have access to significantly more tools and weather information options than they do in-flight. In-flight, they are limited predominantly by the hardware that is installed in their respective aircraft, whether that be avionics packages, onboard radar, or simply an external portable device such as a phone or a tablet. There is no obvious difference among industries with respect to what tools are used, except that some cockpits are better equipped than others, and that the HEMS tool is used predominantly by HAA pilots.

Pilots are predominantly using weather information preemptively. The most important weather check, as described by the pilots, is the preflight weather check. This is largely because it is a deciding factor in whether the mission can be undertaken. In-flight weather information is described to be more supplemental in nature. Pilots indicated that when weather information availability or reliability was reduced, visual scanning was their most important method of gathering in-flight weather information for their current route. The reasoning behind the pilots reliance on visual scanning was simple: it is less cognitively demanding than scanning instruments or looking down at a graphical display.

Although pilots are mostly satisfied with the weather tools they have access to, during the interviews, all pilots pointed several deficiencies in the weather data available to them. First, the data is too coarse spatially, thus pilots often lack information along their route of flight. Second, some weather phenomenon, such as low clouds or fog, are not properly captured by current weather tools. Third, weather forecast can be inaccurate. This explains why pilots use multiple sources of weather information to get a clearer idea of what is happening, and why they rely significantly on their local weather knowledge. This increases the workload for pilots, especially for less experienced ones. Moreover, pilots reported having relatively aggressive weather minimums, which implies a need for more precise weather information as the margins for error are smaller.

The most cognitively difficult aspect of using weather information seems to be when the weather information is either missing or is borderline per the pilots personal or company policies. In these situations, the pilots are forced to enter key decision gates that could potentially alter or cancel the mission being flown. This is especially true in-flight because of the cognitive load of making decisions while piloting the aircraft. It is therefore extremely important that any information being presented to pilots in-flight is not contributing significantly to task saturation. This evidence also suggests that existing in-flight weather technologies may suffer from deficiencies with respect to cognitive overload because the user interfaces are not transferring information efficiently to pilots. To this point, pilots suggested that an effort be made to develop additional weather tools that can be used in-flight without contributing significantly to task saturation. One specific recommendation that was reiterated by multiple pilots was to release a version of the HEMS tool that is usable while in-flight.

There were also certain cultural elements that influenced when and how pilots fly and use weather information in the process. Flying in marginal weather seemed commonplace for all of the pilots and their routine operations. Pilots nearly all mentioned, in some capacity, that personal and/or company weather policies are central to the safety of the operations and to aviation decision-making. These policies attempt to give pilots guidance when making weather-related decisions. It should be noted that personal weather minimums and personal weather policies tended to be significantly more conservative than company policies. Due to this delta between company and personal weather policies, there may be additional external pressure placed on pilots to compromise their own safety minimums in favor of more aggressive company minimums.

VII. Conclusions

The primary objective of this work was to provide a more personal and operator input-driven analysis of weather information gaps in rotorcraft operations. Previous work has been done with the investigation of NTSB accident data to identify weather-related themes for accidents, but this did not give a full picture of the challenges faced by helicopter pilots with respect to weather. By having a more open-ended, conversational interview approach with various operators, the results are driven by the operators and are less dictated by the study expectations or research plan.

The authors utilized two primary methods of data collection, a survey and a set of pilot interviews. A few key themes were identified with regard to how pilots interact with weather information. These themes were sparsity of weather sensing/reporting or lack of weather information, reliance on local or experiential weather knowledge, impact of current technology on safety, external pressures on weather-related decision-making, and distrust of weather information. Based on these themes, we provide the following recommendations:

1) Helicopter pilots would likely benefit from additional weather reporting stations being installed outside of airports and densely populated areas – particularly in areas with significant helicopter activity. Pilots might also benefit from being given access to non-FAA approved weather sources to supplement official weather data.
2) The HEMS tool would be of great use to the entire rotorcraft pilots community and not only to HAA pilots due to its applicability to lower-altitude operations, as explained in section IV.A.
3) Pilots would benefit from the development of tools that more accurately predict and display light precipitation

layers (such as fog) that are typically undetectable by a radar.

4) Pilots would benefit from being presented a coherent overview of current and near-term weather trends via more comprehensive and capable in-flight weather tools (including displays). This would reduce the need to integrate conflicting and out-of date information with prior experience, thereby eliminating sources of cognitive workload.

Appendix I - HOWI Survey

HOWI Operator Survey - Initial

Survey Flow

Standard: Consent (2 Questions)
Standard: Precursor (1 Question)
Standard: Flight Operations (7 Questions)
Standard: Safety of Operations (6 Questions)
Block: Operator Background (11 Questions)
Standard: Follow-Up (3 Questions)

Start of Block: Consent

CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY

Project Title: Use of Weather Information in Rotorcraft Operations

Investigators:
Karen Feigh, Ph.D., Georgia Institute of Technology
Alexia Payan, Ph.D., Georgia Institute of Technology
Barrett Caldwell, Ph.D., Purdue University
You are being asked to be a volunteer in a research study.

Purpose:
The purpose of this study is to better understand what kind of weather information is being used by the rotorcraft community. Specifically, we wish to identify any gaps in weather information availability or barriers to its effective use. We will be asking you a series of questions about your own experience with rotorcraft missions in general and with weather specifically.

Exclusion/Inclusion Criteria:
Multiple classes of participants are sought for this study: Pilots holding a rotorcraft pilot license and employed in or having experience in any of the following domains: Helicopter Emergency Medical Services, Search and Rescue, Law Enforcement, Observation, Air Tour or Air Taxi. Dispatch services to rotorcraft pilots in any of the following domains: Helicopter Emergency Medical Services, Search and Rescue, Law Enforcement, Observation, Air Tour or Air Taxi.

Procedure:
If you decide to participate, you will be presented with a series of questions in an electronic survey. The questions are designed to understand your experiences with rotorcraft operation and how weather impacts you. The questions further focus on how you obtain and use weather information in the execution of your duties as either the pilot or crew of a helicopter or dispatcher to a helicopter and crew. The questions will be presented over a series of pages. You may stop or go back at any point during the survey.

Risks or Discomforts:
No risks are associated with this study beyond that normally experienced when describing past experiences with a colleague or using a computer for routine office work.

Benefits:

You are not likely to benefit in any immediate way from joining this study. However, your participation in this study may assist researchers in understanding how to improve weather information availability and training.

Compensation to You:

No compensation for your time is available.

Storing and Sharing your Information:

Your participation in this study is gratefully acknowledged. It is possible that your information/data will be enormously valuable for other research purposes. By signing below, you consent for your de-identified information/data to be stored by the research team and to be shared with other researchers in future studies. If you agree to allow such future sharing and use, your identity will be completely separated from your information/data. Future researchers will not have a way to identify you. Any future research must be approved by an ethics committee before being undertaken.

Confidentiality:

The following procedures will be followed to keep your personal information confidential in this study: we will comply with any applicable laws and regulations regarding confidentiality. To protect your privacy, your name will not be recorded and your records will be kept under a code number. Your de-identified information may be used for future research without attaining additional consent from you. The Georgia Institute of Technology IRB and the Office of Human Research Protections may look over study records during required reviews.

You should be aware that the experiment is being run from a 'secure' https server of the kind typically used to handle credit card transactions, so the responses are protected from third parties such as hackers. In general, the web page software will log as header lines the IP address of the machine you use to access this page, e.g.,102.403.506.807, but otherwise no other information will be stored unless you explicitly enter it.

Costs to You:

There are no costs to you, other than your time, for being in this study.

○ Yes, I understand and wish to participate

○ No, I do not wish to participate

Skip To: End of Survey If CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY Project Title: Use of Weat... = No, I do not wish to participate

Questions about the Study:

If you have any questions about the study, you may contact Dr. Alexia Payan at alexia.payan@gatech.edu.

Questions about Your Rights as a Research Participant:

Your participation in this study is voluntary. You do not have to be in this study if you don't want to be. You have the right to change your mind and leave the study at any time without giving any reason and without penalty. Any new information that may make you change your mind about being in this study will be given to you. You do not waive any of your legal rights by agreeing to participate.

If you have any questions about your rights as a research participant, you may contact Ms. Melanie Clark, Georgia Institute of Technology Office of Research Integrity Assurance, at (404) 894-6942. *or* Ms. Kelly Winn, Georgia Institute of Technology Office of Research Integrity Assurance, at (404) 385- 2175.

Note that by completing the online survey, you indicate your consent to be in the study.

○ Proceed to survey

○ No, I do not wish to participate

Skip To: End of Survey If Questions about the Study: If you have any questions about the study, you may contact Dr. Alexia... = No, I do not wish to participate

End of Block: Consent

Start of Block: Precursor

Directions: Please, complete this survey as truthfully and as completely as possible. You may refrain from completing any questions you don't feel comfortable answering.
The survey should take approximately 15-20 minutes to complete.
Thank you very much for your participation.

End of Block: Precursor

Start of Block: Flight Operations

What types of terrain are most common for your flight operations?

▢ City

▢ Suburban

▢ Mountainous

▢ Flatland

▢ Coastal

▢ Canyonlands

▢ Forested

▢ Other (Please explain) ____

What types of weather conditions are most common for your flight operations?

▢ Daytime VFR

▢ Nighttime VFR

▢ Instrument Flight Rules (IFR)

▢ Flight with Night Vision Devices (NVD)

▢ Other (Please explain) ____

What weather-related tools and resources do you use during preflight preparation? Please specify your sources.

- ☐ Online weather reports ____
- ☐ Electronic Flight Bag (EFB) ____
- ☐ Preflight weather brief from 3rd party source ______________________________
- ☐ Risk management tools ____
- ☐ Personal electronic device (cell phone, tablet, computer, etc.) _______________
- ☐ Other (Please explain) ____

What weather-related tools and resources do you use for in-flight operations? Please specify your sources.

- ☐ Radio-based weather reporting (AWOS, ASOS, etc.)
- ☐ Flight Service Stations
- ☐ Multi-Function Display (MFD) readouts (NEXRAD, broadcast weather services, etc.)
- ☐ Personal electronic device readouts (phone/tablet applications, etc.)
- ☐ Dispatch communications
- ☐ Other (Please explain) ____

Do you feel that you currently have access to all relevant weather-related information and/or tools required to conduct and/or support your operations? If not, please explain.

- ○ Yes
- ○ No ____

Do you believe that the type(s) of weather-related information/tools you currently use and/or have access to are relevant and sufficient to conduct safe operations? If not, please explain.

- ○ Yes
- ○ No ____

Do you believe that the latency in the tools that you currently use to obtain weather-related information may be a hindrance to conducting safe operations? If yes, please explain.

- ○ Yes ____
- ○ No

End of Block: Flight Operations

Start of Block: Safety of Operations

Do you know of any examples of someone having encountered or come close to encountering any of these adverse weather conditions, regardless of purpose of flight?

- ☐ Low cloud ceiling
- ☐ Heavy precipitation
- ☐ High winds
- ☐ Wind shift
- ☐ Gusts/Turbulence
- ☐ Microbursts
- ☐ Heavy fog
- ☐ Freezing temperatures
- ☐ Icing
- ☐ Mountain obscuration
- ☐ Mountain wave
- ☐ Flat light/Whiteout
- ☐ Whiteout/Brownout
- ☐ Other (Please specify) ____
- ☐ None

Skip To: End of Block If Do you know of any examples of someone having encountered or come close to encountering any of th... = None

Display This Question:

If Do you know of any examples of someone having encountered or come close to encountering any of th... != None

Did this encounter with any of the previously mentioned adverse weather conditions lead to a reportable aviation 'incident' or 'accident'? If yes, please list the cause.
{Low cloud ceiling, Heavy precipitation, High winds, Heavy fog, Freezing temperatures, Mountain obscuration, Whiteout/Brownout, Other}

- ◯ Yes - Incident (Please explain) ____________________
- ◯ Yes - Accident (Please explain) ____________________
- ◯ No

Skip To: End of Block If Did this encounter with any of the previously mentioned adverse weather conditions lead to a repo... = No

Please briefly explain the event that led to the incident or accident.

____

Were there any external factors involved at the time of the event? If so, please use the slider bars to quantify the impact that this had on your operations.

	0	1	2	3	4	5	6	7	8	9	10
Mission Urgency											
Job Retention											
Desire to "do the right thing"											
Personal Emergency											
VIP or Patient Transport											
Other (Please explain)											

Do you believe that the crew were adequately prepared to handle the event? If no, please explain.

- ◯ Yes
- ◯ No ____________________

What type of intervention do you believe could have prevented the event from occurring?

____

End of Block: Safety of Operations

Start of Block: Operator Background

What is your age range?

○ Under 25

○ 25-40

○ 41-55

○ 56-70

○ 71+

What is your operational duty? Select all that apply and fill in how many years you have been in this position.

☐ Pilot ____

☐ Crew ____

☐ Dispatcher ____

☐ Other (Please Explain) ____

If you are a pilot, what is your piloting experience? Select all that apply and fill in how many flight hours you currently have toward each rating.

☐ Rotorcraft Pilot ____

☐ Fixed-Wing Pilot ____

☐ Other (Please explain) ____

☐ Not a Pilot

Display This Question:

If If you are a pilot, what is your piloting experience? Select all that apply and fill in how many... != Not a Pilot

Do you hold an instrument rating? Select all that apply and fill in how many hours of instrument time you hold.

☐ Rotorcraft Instrument Rating ____

☐ Fixed-Wing Instrument Rating ____

☐ None

Display This Question:

If Do you hold an instrument rating? Select all that apply and fill in how many hours of instrument... != None

Are you current on your instrument rating? Select all that apply.

- ☐ Yes, current for Helicopter Instrument
- ☐ Yes, current for Fixed-Wing Instrument
- ☐ Not current on Instrument Rating

Display This Question:

If If you are a pilot, what is your piloting experience? Select all that apply and fill in how many... = Rotorcraft Pilot

Did you receive training on how to recover from spatial disorientation or Inadvertent Instrument Meteorological Conditions (IIMC) in a rotorcraft?

- ○ Yes
- ○ No
- ○ I don't remember

Display This Question:

If Did you receive training on how to recover from spatial disorientation or Inadvertent Instrument... = Yes

What type of training did you receive? (Please select all that apply)

- ☐ Classroom Instruction
- ☐ In-Flight Training
- ☐ Simulator
- ☐ Military Training
- ☐ Civil/Commercial Training
- ☐ Other (Please specify) ____

Display This Question:

If Did you receive training on how to recover from spatial disorientation or Inadvertent Instrument... = Yes

When were you last trained to recover from spatial disorientation or IIMC?

- ○ Less than 6 months ago

◯ Between 6 months and 1 year ago

◯ Between 1 and 2 years ago

◯ More than 2 years ago

Display This Question:

If If you are a pilot, what is your piloting experience? Select all that apply and fill in how many... = Rotorcraft Pilot

What classes of rotorcraft do you have experience with? Select all that apply and fill in how many hours you currently have for each type.

- ☐ Single Main Rotor ____
- ☐ Tandem Rotors ____
- ☐ Intermeshing Rotors ____
- ☐ Coaxial Rotors ____
- ☐ Other (Please explain) ____

Display This Question:

If If you are a pilot, what is your piloting experience? Select all that apply and fill in how many... = Fixed-Wing Pilot

What classes of fixed-wing aircraft do you have experience with? Select all that apply and fill in how many hours you currently have for each type.

- ☐ Single-Engine (Piston) ____
- ☐ Multi-Engine (Piston) ____
- ☐ Turbine ____
- ☐ Other (Please explain) ____

In what operational domain is your experience? Select all that apply and fill in how many years of experience you have in that domain.

- ☐ Emergency Medical Services or Air Ambulance ____________________________
- ☐ Search & Rescue ____
- ☐ Aerial Observation or Surveillance ____

☐ Commercial Air Tour or Air Taxi ____

☐ Military ____

☐ Private or Recreational ____

☐ Other (Please explain) ____

End of Block: Operator Background

Start of Block: Follow-Up

Would you be interested in continuing your participation in this study?

○ Yes

○ No

Display This Question:

If Would you be interested in continuing your participation in this study? = Yes

And Did this encounter with any of the previously mentioned adverse weather conditions lead to a repo... != No

Would you be willing to participate in an interview with a researcher to gain a better understanding of the weather-related event you were involved in?

○ Yes

○ No

Display This Question:

If Would you be interested in continuing your participation in this study? = Yes

Or Would you be willing to participate in an interview with a researcher to gain a better understand... = Yes

Thank you for your interest in assisting us with this study! Please fill in your contact information below (one method is sufficient) and we will reach out to you at a later date!

☐ Email Address ____

☐ Phone Number ____

End of Block: Follow-Up

Appendix II - HOWI Operator Interview Questions Set

This document provides the structure for interviewing helicopter pilots. The structure is mostly taken from the ACTA approach developed by Militello and Hutton [11], and the timeline construction was taken from the Critical Decision Method approach [18]. The interview below should take an estimated time of 3 hours.

Introduction: Thank you for making yourself available today. We will cover part I or II or III of the interview today. Please go over the consent form and let me know if you have any questions. You may leave the study at any time in case of an emergency or if you are uncomfortable. We will be recording audio. (After consent)

Stage 1: Surface-level interview and task diagram

- Please describe the main types of missions you fly at a very high level. *Interviewer must pick one of these to focus on.*
- Thinking specifically about [this] type of mission, can you break this mission down into 3 to 6 steps? Please make sure to specify how and when you access or take into account weather information unless you do not, then please just let me know that.
- Now, among the steps that you have identified here, what ones are cognitively difficult? In other words, what are the steps that involve thinking, judging, problem solving, decision-making or assessments?
- Going deeper are any of the steps that involve gathering, manipulating or considering weather cognitively difficulty? How so?
- How does this change with degraded visual conditions?

Stage 2: Weather incident overview

- Think of a particular scenario in which the weather significantly altered your standard operating procedures for the given mission? Could you please draw a timeline of that mission?
- Could you please give me a brief overview of the weather information you attended to, how you obtained it, if you needed to manipulate it in any way, or if you had to project it into the future. Please indicate this on the timeline.
- Could you please give me a brief overview of any aspects of the technology that made performing the mission particularly difficult? Please indicate this on the timeline.
- Think of a particular scenario in which [a different type of weather] significantly altered your standard operating procedures for the given mission? Could you please draw a timeline of that mission?
- Could you please give me a brief overview of the weather information you attended to, how you obtained it, if you needed to manipulate it in any way, or if you had to project it into the future for this other scenario. Please indicate this on the timeline.
- Could you please give me a brief overview of any aspects of the technology that made performing this other scenario particularly difficult? Please indicate on the timeline.

Stage 3: Knowledge audit

- Maintaining a big picture view of a mission can be important. What do you pay attention to, in order to maintain the big picture? Thinking specifically about weather, what do you pay attention to in order to maintain situational awareness of the weather and its impact on the mission?
- As the pilot, you are often the point person on the overall mission team. You may also have had an experience of noticing something that others did not during the mission. Could you give an example of such an experience where you noticed something that popped out at you and that others did not notice? Any weather-related examples come to mind?
- When you perform a mission, are there ways of working smartly, efficiently, or accomplishing more with less - that you have found useful? This could be an example of something that saves time, resources, or reduces workload. Can you give any examples with specific relationship to weather information?
- Following from the previous question, can you think of any equipment that made things easier, especially under challenging weather conditions?
- Can you think of an example when you have improvised something on your own in this task or noticed an opportunity to do something better or different from what was prescribed in standard operating procedures or manuals? Any weather-related examples come to mind?
- Have you experienced a situation where you realized on your own that your performance on the mission was not what it should have been and decided to change the way you were performing in order to get the job done? What

made you realize this situation?

- Can you describe an instance when you spotted a weather-related deviation from the norm, or knew something was amiss? What made you notice this?
- Equipment can sometimes be misleading. Have there been situations when the equipment in the cockpit gave you information that you disregarded and instead proceeded with your own judgment based on your own experience? What made you disregard it? Any weather-related examples come to mind?

Conclusion: Thank you very much for your time. Your data is very valuable for the study. If you have any questions or concerns about the study, please do not hesitate to contact [Interviewer / Prof. Karen Feigh]. Thanks again.

VIII. Appendix III - Interview Transcription Evidence Categories

How are pilots using weather information?

1) Does it differ among different stages of flight?
2) Does it depend on the type of mission?
3) Does it depend on the pilots expectations for the flight?

What is cognitively difficult about the pilots' use of weather information?

1) Do they have to transform multiple pieces of weather information to get a full picture?
2) Do they have to project weather information into the future?
3) Do they have to take into account the latency of certain weather information sources?
4) Is the weather information too coarse for it to be useful?
5) Conflicting, missing, or incorrect weather information?

What are the cultural elements that influence their seeking and use of weather information?

1) Standard operating procedures?
2) Single vs. dual pilot operations?
3) Personal, habitual, or training-related?
4) External pressures?
5) Local knowledge?

Were there any common themes among weather incidents?

1) Technological?
2) Company or personal weather policy?
3) Conflicting, missing, or incorrect weather information?
4) Erroneous pilot expectations?
5) Weather information misinterpretation?
6) Company or personal willingness to self-assess during or post-flight?
7) Company or personal response?

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